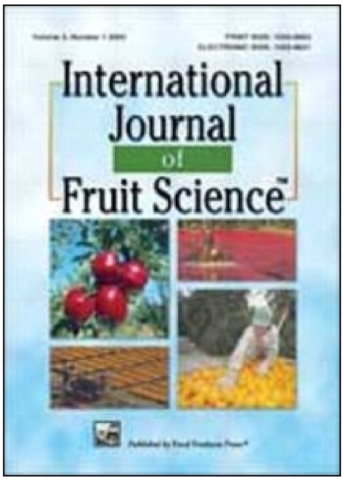

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Anil Shrestha [a]; Greg T. Browne [b]; Bruce D. Lampinen [c]; Sally M. Schneider [d]; Thomas J. Trout [e]
[a] Department of Plant Science, California State University, Fresno, California, USA [b] USDA-ARS, Dept. of Plant Pathology, University of California, Davis, California, USA [c] Dept. of Plant Sciences, University of California, Davis, California, USA [d] Horticulture, Pathogens and Germplasm, USDA-ARS, Beltsville, Maryland, USA [e] USDA-ARS, Water Management Research, Fort Collins, Colorado, USA

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Weed Community Composition in Tree Fruit Nurseries Treated with Methyl Bromide and Alternative Fumigants

ANIL SHRESTHA[1], GREG T. BROWNE[2], BRUCE D. LAMPINEN[3], SALLY M. SCHNEIDER[4], and THOMAS J. TROUT[5]

[1]*Department of Plant Science, California State University, Fresno, California, USA*
[2]*USDA-ARS, Dept. of Plant Pathology, University of California, Davis, California, USA*
[3]*Dept. of Plant Sciences, University of California, Davis, California, USA*
[4]*Horticulture, Pathogens and Germplasm, USDA-ARS, Beltsville, Maryland, USA*
[5]*USDA-ARS, Water Management Research, Fort Collins, Colorado, USA*

Many agricultural cropping systems have relied on methyl bromide (MeBr) for pest control, including weeds, for decades. Alternative fumigants are being sought worldwide because MeBr has been identified as an ozone-layer depleting substance. Weed communities respond dynamically to alterations in management systems. Thus, transition from MeBr to alternative fumigants may cause shifts in weed communities. This hypothesis was tested in four commercial fruit nurseries in California, USA. Treatments included nonfumigated control, MeBr (98%), iodomethane (50%) + chloropicrin (50%), 1,3-dichloropropene (1,3-D), 1,3-D (61%) + chloropicrin (35%), and 1,3-D (62%) + chloropicrin (35%) applied subsurface. All the fumigants reduced the population of common major weed species and had similar species composition as MeBr. None of the fumigants, including MeBr, controlled species such as Medicago polymorpha, Lotus purshianus, Malva parviflora, Conyza sp., Senecio vulgaris, and Sonchus oleraceus. This study suggested that, fruit nurseries transitioning from MeBr to alternatives may not see an immediate shift in weed communities.

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Address correspondence to Anil Shrestha. E-mail: ashrestha@csufresno.edu

However, Additional weed control measures will be required to manage weed species of the Asteraceae, Fabaceae, and Malvaceae family that are not controlled by either MeBr or the alternate fumigants.

KEYWORDS *methyl bromide, montreal protocol, ozone, weed species shifts*

INTRODUCTION

Methyl bromide (MeBr) has been a popular tool in the perennial crop nurseries of California, USA, for broad-spectrum control of numerous pests, including weeds (Hanson and Shrestha, 2006). With the phase-out of MeBr, following the 1987 "Montreal Protocol on Substances that Deplete the Ozone Layer" (UNEP, 2000; USDA, 2000), researchers are seeking short- and long-term alternatives to MeBr in many cropping systems worldwide, including perennial crop nurseries in California (Hanson and Shrestha, 2006). Changes in management practices often lead to weed species shifts (Buhler, 2003). Therefore, transition to alternative fumigants in perennial nurseries that have, for decades, been treated with MeBr may cause changes in weed communities.

Changes in weed communities toward species that are more difficult to control may have deleterious effects, particularly in high-value perennial crop nurseries in California where alternate economic pest control methods or registered herbicides are currently lacking (Hanson and Shrestha, 2006). For example, in these perennial nurseries there are several difficult to control weed species, such as *Cyperus* sp., that have been adequately controlled by MeBr (Rosskopf et al., 2000; Gilreath and Santos, 2004). If alternatives to MeBr fail to control the major weeds, shifts may occur toward these species and necessitate additional control measures. Any additional weed control measure could result in substantial increases of cultural costs to the grower. Further, nurseries in California are required to produce pest- and pathogen-free rootstocks to meet the sanitation standards set for state certification of nursery crops (CDFA, 2001). Several weed species can act as alternate hosts or harbor harmful insects, pathogens, nematodes, or rodents (Radosevich et al., 1997), therefore, thresholds for weeds may be zero or very low in perennial nurseries.

Several alternative fumigants have been tested with varied effects on different weed species. For example, chloropicrin provided good control of species such as *Stellaria media* L. Vill., *Geranium carolinianum* L., *Gnaphalium purpureum* L., *Oenothera laciniata* Hill. (Csinos *et al.* 2000), *Cyperus esculentus* L. (Hutchinson et al., 2004), *Polygonum aviculare* L., and *Portulaca oleracea* L. (Haar et al., 2003). However, this fumigant provided poor control of *Malva parviflora* L. and *Erodium cicutarium* (L.) L'Hér. ex Ait (Haar et al., 2003). The alternate fumigant 1,3-dichloropropene (1,3-D) provided good control of *Cyperus* sp. (Gilreath et al., 2005; Chase et al., 2006), *Ipomoea* sp., and several other annual weeds such as *Amaranthus retroflexus* L. (Unruh et al., 2002), but was weak against *Cynodon dactylon* L. Pers. and *Mollugo verticillata* L. (Unruh et al., 2002). A commercial formulation of 1,3-D (61%) + chloropicrin (33%) also has been tested as a MeBr replacement. A laboratory study found that the seeds of *P. oleracea* were the most sensitive to this fumigant, followed by *S. media* and *Polygonum arenastrum* Boreau. The seeds of *M. parviflora* and *E. cicutarium* were not sensitive to fumigation up to the highest dose of 19,520 μmol kg^{-1} soil (Klose et al., 2007).

Although not currently registered in the USA, iodomethane (methyl iodide) has also been included in the list of potential alternatives to MeBr for weed control (Noling, 2000). Iodomethane controlled several grass weed species, sedges, and broadleaf weeds in turf (Unruh et al., 2002). Zhang et al. (1997) reported good control of *A. retroflexus* with iodomethane and found that it was more potent than MeBr on *Lolium multiflorum* Lam., *Abutilon theophrasti* Medik., *Chenopodium album* L., *P. oleracea*, *Brassica kaber* (DC.) L.C. Wheeler, *C. esculentus,* and *C. rotundus* L. but was weak against *Solanum nigrum* L.

Most of the species listed in the above examples are common weeds of perennial fruit nurseries in California and the findings suggest that the alternative fumigants may better control some species over others. This selective process may cause shifts in species toward a dominant community of certain weeds that are not adequately controlled by the fumigants. However, the effect of alternative fumigants on weed communities in perennial nursery cropping systems is not known. Therefore, the objective of this study was to assess the effect of several alternative fumigants on weed community composition and predicted species shifts.

MATERIALS AND METHODS

Experiments were conducted at four commercial perennial crop nurseries in cities in California, USA: Oakdale, Yuba City, Le Grand, and Hickman, CA. The soil type at Oakdale is a Typic Xerorthent with a coarse loamy texture (68% sand, 20% silt, 12% clay); at Yuba City it is a Typic Argixerolls with a fine texture (39% sand, 37% silt, 24% clay); at Le Grand it is a Abruptic Durixeralfs with a fine texture (43% sand, 40% silt, 17% clay); and at Hickman it is a Typic Haploxeralfs with a coarse loamy texture (66% sand, 23% silt, 11% clay). The experiment was conducted from August 2003 to December 2004 at Oakdale, September 2003 to December 2005 at Yuba City, May 2004 to December 2005 at Le Grand, and August 2004 to August

2006 at Hickman. These experimental durations were based on the standard practices of the nurseries for nursery stock production. The nursery crop at Yuba City was black walnut (*Juglans nigra* L.), whereas at the other three locations it was almond [*Prunus dulcis* (Mill.) D. A. Webb.] Details on aspects of crop planting and crop husbandry are not discussed in this paper.

In each location, the experimental design was a randomized complete block with four replications. Individual plot sizes were 27.4 by 7.6 m, 27.4 by 10 m, 26.2 by 10 m, and 26.2 by 10 m at Oakdale, Yuba City, Le Grand, and Hickman, respectively. The plots were fumigated with different fumigants and covered immediately with either high density polyethylene (HDPE) film (Tyco Plastics, Princeton, NJ, USA) or virtually impermeable film (VIF; Bruno Riminni Ltd., London, UK). Nonfumigated plots were also included in each location. The fumigant treatments were: (a) Methyl Bromide (98%) [MeBr] at 448 kg ha^{-1}, covered with HDPE film; (b) iodomethane (50%) + chloropicrin (50%) [IM:PIC] at 448 kg ha^{-1}, covered with HDPE film; (c) 1,3-dichloropropene [1,3-D] (Telone II ®, Dow AgroSciences, Indianapolis, IN, USA) at 380 kg ha^{-1}, covered with HDPE film; (d) 1,3-D (61%) + chloropicrin (35%) [1,3-D:PIC] (Telone C-35®, Dow AgroSciences, Indianapolis, IN, USA) at 600 kg ha^{-1}, covered with HDPE film; (e) 1,3-D (62%) + chloropicrin (35%) [1,3-D:PIC(I)] (Inline®, Dow AgroSciences, Indianapolis, IN, USA) at 600 kg ha^{-1}, covered with HDPE film; and (f) 1,3-D (61%) + chloropicrin (35%)' [1,3-D:PIC] (Telone C-35®, Dow AgroSciences, Indianapolis, IN, USA) at 600 kg ha^{-1}, covered with VIF. At Oakdale, the 1,3-D:PIC (I) treatment was excluded, and at Yuba City the 1,3-D and the 1,3-D:PIC(I) treatments were excluded.

The MeBr and IM:PIC treatments were injected with a Noble plough rig (Trical Inc., Hollister, CA, USA). The injection depth was 30 cm with 30 cm nozzle spacing. The 1,3-D and the 1,3-D:PIC treatments were injected with a Telone rig (Trical Inc., Hollister, CA, USA). The injection depth was 45 cm with 30 cm nozzle spacing. The 1,3-D:PIC(I) treatment was applied subsurface through a thin-walled drip-tape (Netafim USA, Fresno, CA, USA) buried 15 cm deep. The drip tape with emitters spaced 30 cm apart had a flow rate of 0.9 L hr^{-1} at 1 bar. The tapes were placed 60 cm apart in the plots to obtain a broadcast treatment over the entire plot. The 1,3-D:PIC (I) was injected for 18 hours into the drip irrigation system from a nitrogen-pressurized cylinder containing the fumigant. The fumigants were applied on September 2, and September 9, 2003 at Oakdale and Yuba City, respectively, and on May 13, and August 6, 2004 at Le Grand and Hickman, respectively. The films were removed one to two weeks after fumigation. Raised beds (approximately 30 cm high) were formed after the films were removed. The beds were 45 cm wide at Oakdale and Yuba City, and 30 cm wide at Le Grand and Hickman. Therefore, there were 5 to 7 crop rows (beds) in each plot depending upon the locations.

At Oakdale, an application of 1.12 kg ha^{-1} isoxaben (Gallery®, Dow AgroSciences, Indianapolis, IN, USA) plus 0.46 kg ha^{-1} pendimethalin (Prowl®, BASF, Research Triangle Park, NC, USA) was made on April 15, 2004. At Yuba City, a preemergent application of 4.48 kg ha^{-1} oryzalin (Surflan®, United Phosphorus Inc., Trenton, NJ, USA) was made on October 29, 2003 immediately after planting the nursery crop followed by an application of 0.9 kg ai ha^{-1} glyphosate (Roundup®, Monsanto, St. Louis, MO, USA) on February 15, 2004 prior to crop emergence. At Le Grand, 0.8 kg ha^{-1} paraquat (Gramoxone®, Syngenta, Greensboro, NC, USA) was applied on January 6, 2006 prior to emergence of the nursery crop whereas in Hickman, 0.9 kg ai ha^{-1} glyphosate was applied on November 16, 2004 prior to nursery crop emergence. No other herbicides were applied during the study. These herbicide applications were based on the standard practices of each nursery.

In each plot, a crop row (bed) was selected at random. All the weeds in a strip 45 cm wide by the length of the plot were counted by species and then removed with a hoe every 2 to 3 months. We counted weeds at Oakdale in 2004 during February, March, June, September, and November. At Yuba City, the evaluations were done in 2004 during January, March, May, July, September, and in 2005 during March, June, and December. At Le Grand, evaluations were done in 2005 during January, March, June, August, and November. And at Hickman, the evaluations were done in November 2004, March, May, and October of 2005, and in April and July 2006. Care was taken to remove every emerged weed in the hand-hoeing process to avoid escapes that could otherwise result in counting of the same weeds in successive evaluations. The remaining rows in each plot were hand weeded by the nursery field crew after evaluations on the data row were completed. No weed evaluations were made in the inter-row space which was mechanically cultivated several times during the growing season or seasons at all sites.

Weed densities by species at each location were pooled by season: spring (March 20–June 20), summer (June 21–September 22), fall (September 22–December 20), and winter (December 21–March 19), based on the sampling time. Data were analyzed using different procedures in SAS (Statistical Analysis System Software, Version 9.1.3, SAS Institute Inc., Cary, NC, USA). Homogeneity of variance was tested with the Shapiro-Wilk test using PROC UNIVARIATE. Average weed density by species in each treatment was assessed by PROC MEANS. Those weed species that were present in average densities greater than 1 plant m^{-2} at each location were identified and included for further analysis using PROC GLM. Several conventional transformations failed to improve homogeneity of variance, so analysis was performed on nontransformed data and means were separated using the Fisher's Protected LSD at $P = 0.05$ level of significance.

RESULTS AND DISCUSSION

Weed community composition was fairly diverse across the four study locations. Altogether, 53 weed species were observed in the study of which only 10 were present in all locations (Table 1). The species common to all nurseries included *Amaranthus* sp., *Sonchus oleraceus* L., *Medicago polymorpha* L., *S. media*, *Senecio vulgaris* L., *Conyza* sp. (*C. canadensis* and *C. bonariensis*), *Erodium* sp., *M. parviflora*, *Lactuca serriola* L., and *Raphanus raphanistrum* L. The diversity of weed species was greatest (34) at Hickman. The total number of weed species recorded at Oakdale, Yuba City, and Le Grand was 29, 26, and 23, respectively. Although the species provide an idea of weed communities at these sites, there may have been seeds of other species present in these locations that were dormant during the experimental years. Nevertheless, the species sampled is fairly representative of the major weeds in the perennial nurseries in the Central Valley of California. Pre-emergent herbicide applications at Oakdale and Yuba City may have compromised some results on weed species composition. However, the weed species at Oakdale were very low, whereas at Yuba City, the experiment was conducted over two years and the preemergent herbicides may have lost their efficacy by the second year of the study. This statement can be supported by the quantity of emerging weeds over the duration of the studies at all locations except Oakdale, details of which are reported in Shrestha et al. (2008).

The weed species present in greatest densities at Oakdale were *Conyza* sp., *Lotus purshianus* L., *P. oleracea*, *R. raphanistrum*, and *S. oleraceus* (Table 2). In general, the average densities of these weeds were similar between the fumigated treatment areas, but lower than the nonfumigated control plots. *Conyza* sp. was present in similar ($P > 0.05$) numbers in all the treatments in spring and winter. Similarly, none of the fumigants controlled *L. purshianus*. This latter species belongs to the Fabaceae family in which seeds of most species have an impermeable seed coat that imposes a physical exogenous dormancy (Van Assche et al., 2003). The fumigants, thus, may not have penetrated the seed coats of *L. purshianus*.

In spring, *P. oleracea* was controlled by all the fumigants. The fumigated plots had no further emergence of *P. oleracea* in summer, whereas a few plants emerged in the nonfumigated plots (Table 2). Similarly, all the fumigated plots had lower densities of *R. raphanistrum* in winter. Thus, it can be inferred that all the fumigants provided similar control of *P. oleracea* and *R. raphanistrum*, but none of the treatments controlled *Conyza* sp., *L. purshianus*, and *S. oleraceus* over the duration of this experiment. Therefore, at this location, these latter species may continue to be a problem even with the use of MeBr or alternative fumigants.

At Yuba City, the weed species that were present in the greatest densities included volunteer *Avena sativa* L. plants, *Capsella bursa-pastoris* L.,

TABLE 1 Species Name, Life Cycle, and Family Name of Weeds Present at Each Study Location

			Location			
			Presence/Absence			
Species	Life cycle	Family	Oakdale	Yuba City	Le Grand	Hickman
Amaranthus sp.	A	Amaranthaceae	+	+	+	+
Amsinckia intermedia	A	Boraginaceae	-	+	-	-
Anagallis arvensis	A	Primulaceae	-	-	-	+
Anthemis cotula	A	Asteraceae	+	-	-	+
Avena sativa	A	Poaceae	-	+	-	-
Brassica sp.	A	Brassicaceae	-	+	-	-
Bromus sp.	A	Poaceae	-	+	-	-
Calandrinia ciliata	A	Portulacaceae	-	+	+	-
Capsella bursa-pastoris	A	Brassicaceae	+	+	+	+
Cerastium fontanum	A	Caryophyllaceae	-	-	-	+
Chamaesyce maculata	A	Euphorbiaceae	-	-	-	+
Chamomilla suaveolens	A	Asteraceae	+	-	-	-
Chenopodium album	A	Chenopodiaceae	+	-	-	-
Claytonia perfoliata	A	Portulacaceae	-	+	-	-
Convolvulus arvensis	P	Convolvulaceae	-	+	+	+
Conyza sp.	A	Asteraceae	+	+	+	+
Coronopus didymus	A	Brassicaceae	-	-	-	+
Cyperus esculentus	P	Cyperaceae	+	-	+	+
Cynodon dactylon	P	Poaceae	-	-	-	+
Digitaria sanguinalis	A	Poaceae	+	-	+	+
Echinochloa colona	A	Poaceae	-	-	+	-
Echinochloa crus-galli	A	Poaceae	-	+	-	-
Epilobium sp.	A	Onagraceae	+	-	+	+
Erodium sp.	A	Geraniaceae	+	+	+	+
Galium sp.	A	Rubiaceae	-	-	+	+
Gnaphalium sp.	A	Asteraceae	-	+	+	+
Hemizonia fitchii	A	Asteraceae	+	-	-	-
Hypochaeris radicata	A	Asteraceae	+	-	+	-
Juncus bufonius	A	Juncaceae	-	-	-	+
Lactuca serriola	A	Asteraceae	+	+	+	+
Lamium amplexicaule	A	Lamiaceae	-	+	+	+
Lotus purshianus	A	Fabaceae	+	-	-	+
Lupinus sp.	A	Fabaceae	-	+	-	-
Malva parviflora	A	Malvaceae	+	+	+	+
Medicago polymorpha	A	Fabaceae	+	+	+	+
Melilotus officinalis	A	Fabaceae	+	-	-	-
Oxalis corniculata	A	Oxalidaceae	-	-	-	+
Panicum capillare	A	Poaceae	+	-	-	-
Poa annua	A	Poaceae	+	+	-	+
Polygonum arenastrum	A	Polygonaceae	+	-	-	+
Portulaca oleracea	A	Portulacaceae	+	-	+	+
Raphanus raphanistrum	A	Brassicaceae	+	+	+	+
Salsola tragus	A	Chenopodiaceae	+	-	-	+
Senecio vulgaris	A	Asteraceae	+	+	+	+
Solanum nigrum	A	Solanaceae	+	+	-	-
Sonchus oleraceus	A	Asteraceae	+	+	+	+
Sorghum halepense	P	Poaceae	-	+	-	-

(*Continued*)

TABLE 1 (*Continued*)

Species	Life cycle	Family	Location: Presence/Absence Oakdale	Yuba City	Le Grand	Hickman
Vicia sativa	A	Fabaceae	+	+	–	–
Sorghum halepense	P	Poaceae	–	+	–	–
Spergula arvensis	A	Caryophyllaceae	+	–	–	–
Stellaria media	A	Caryophyllaceae	+	+	+	+
Taraxacum officinale	P	Asteraceae	–	–	–	+
Tribulus terrestris	A	Zygophyllaceae	–	–	+	+
Veronica persica	A	Scrophulariaceae	–	–	–	+
Vicia sativa	A	Fabaceae	+	+	–	–

A = Annual; P = Perennial.
+ = Species present at the location; – = species absent at the location.

TABLE 2 Seasonal Densities of Major Weed Species at Oakdale, CA

Species	Treatment[a] Control	MeBr	IM:PIC	1,3-D	1,3D:PIC-HDPE	1,3-D:PIC-VIF	*P*-value
Density[†] (plants m^{-2})							
Spring							
Conyza sp.	0.0	0.5	0.0	0.0	0.8	2.0	0.72
Lotus purshianus	1.0	0.8	1.3	1.3	0.3	1.3	0.81
Portulaca oleraceae	2.0a	0.0b	0.0b	0.0b	0.0b	3.0b	0.05
Summer							
Portulaca oleraceae	1.0a	0.0b	0.0b	0.0b	0.0b	0.0b	0.009
Fall							
Sonchus oleraceus	2.0	1.2	1.0	1.3	2.1	1.3	0.85
Winter							
Conyza sp.	1.1	0.2	0.2	0.5	0.3	0.8	0.40
Lotus purshianus	1.5	1.4	1.4	2.7	1.6	1.8	0.84
Raphanus raphanistrum	1.2a	0.1b	0.2b	0.2b	0.1b	0.1b	0.02

[†]Means within a row followed by the same letter do not differ at the 5% level of significance of Fisher's Protected LSD test.

Poa annua L., *S. vulgaris*, *S. oleraceus*, *Sorghum halepense* L., and *S. media* (Table 3). *Avena sativa* was the previous crop at this site and it emerged as volunteers throughout the year. The density of this species was greater in the nonfumigated compared to the fumigated plots, but had similar density in the fumigated plots. In spring, the density of *C. bursa-pastoris* was similar between the fumigated plots but lower than the nonfumigated plots (Table 3). Other species such as *P. annua* and *S. media* were present in similar densities

TABLE 3 Seasonal Densities Of Major Weed Species at Yuba City, CA

	Treatment[a]					
Species	Control	MeBr	IM:PIC	1,3D:PIC - HDPE	1,3D:PIC - VIF	*P*-value
Density† (plants m^{-2})						
Spring						
Avena sativa	13.9a	1.2b	3.4b	3.3b	2.0b	0.01
Capsella bursa-pastoris	2.3a	0.0b	0.0b	0.1b	0.0b	0.05
Poa annua	5.0a	0.1b	0.6b	0.7b	0.2b	0.01
Sonchus oleraceus	3.2	1.2	1.2	1.2	1.5	0.45
Stellaria media	2.1a	0.0b	0.2b	0.6b	0.2b	0.01
Summer						
Avena sativa	2.6a	0.0b	0.2b	0.6b	0.2b	0.02
Capsella bursa-pastoris	0.9	0.5	1.1	0.1	0.6	0.49
Senecio vulgaris	0.9	2.1	2.1	1.8	2.4	0.56
Sonchus oleraceus	4.6	1.9	4.5	2.1	3.6	0.36
Sorghum halepense	2.0	0.1	2.2	0.1	0.1	0.07
Fall						
Avena sativa	44.6a	1.7b	5.2b	6.4b	2.5b	<0.0001
Senecio vulgaris	0.5	2.2	1.4	0.3	0.5	0.47
Sonchus oleraceus	2.8	0.3	0.9	0.5	1.2	0.26
Stellaria media	16.3a	1.1b	6.4b	6.8b	3.3b	0.01
Winter						
Senecio vulgaris	0.5	2.1	1.4	0.2	0.4	0.48
Stellaria media	13.3a	1.0c	5.9b	6.2b	3.1b	0.05

†Means within a row followed by the same letter do not differ at the 5% level of significance of Fisher's Protected LSD test.

in the fumigated plots but were lower than the nonfumigated plots. *Sonchus oleraceus* was present in every season at this location and its densities were similar ($P > 0.05$) in all the treatment plots.

In the summer, *S. vulgaris* were observed in similar ($P > 0.05$) densities in all the plots (Table 3). In fall, *A. sativa* and *S. media* were the major weed species but all the fumigants provided similar control of these species (Table 3). *Stellaria media* continued to be present in winter. Although the densities were lower in the fumigated plots, the alternative fumigants were not as effective as MeBr in controlling this species. This may be because the experiment at this location was continued for two years and by the end of the experiment the alternative fumigants may have lost their ability to control this species compared to MeBr.

At this location, the fumigants provided similar control of most species but none of the fumigants provided adequate control of Asteraceae weeds such as *Conyza* sp., *S. oleraceus*, and *S. vulgaris*. Although some seeds may have been present in the plots during fumigation, the seeds of these species are light and fluffy and can travel with air currents (Andersen, 1993; Shields et al., 2006). Therefore, wind blown seeds may have reinfested the plots following fumigant application. Thus, similar to Oakdale, additional control will be required for Asteraceae weeds at this location even with the use of MeBr or alternate fumigants.

At Le Grand, the major weed present in spring was *M. parviflora* and its density was similar in all the plots indicating that none of the fumigants provided control of this species (Table 4). In summer, *P. oleracea* and *Echinochloa crus-galli* were the major weeds. Although similar control of *E. crus-galli* was obtained by all the fumigants, differences were observed between the fumigants in the control of *P. oleracea*. Better control of *P. oleracea* was obtained with 1,3-D and 1,3-D:PIC treatments compared to MeBr, whereas IM:PIC provided similar control as MeBr and the other fumigants.

TABLE 4 Seasonal Densities of Major Weed Species at Le Grand, CA

	Treatment[a]							
Species	Control	MeBr	IM:PIC	1,3-D	1,3D:PIC - HDPE	1,3D: PIC(I)	1,3D:PIC - VIF	*P*-value
Density[†] (Plants m^{-2})								
Spring								
Malva parviflora	1.7	2.2	0.6	1.2	0.8	0.5	0.6	0.42
Summer								
Portulaca oleracea	9.3a	4.4b	2.1bc	1.3c	0.8c	1.2c	0.1c	<0.0001
Echinochloa crus-galli	1.6a	0.2b	0.0b	0.0b	0.1b	0.0b	0.0b	0.0004
Fall								
Capsella bursa-pastoris	1.1	0.1	0.1	0.4	0.0	0.1	1.6	0.53
Conyza sp.	0.0	0.0	0.2	0.1	0.3	0.3	1.0	0.59
Echinochloa crus-galli	1.7a	0.2b	0.0b	0.0b	0.0b	0.0b	0.0b	0.0004
Lamium amplexicaule	2.9a	0.0b	0.1b	0.2b	0.2b	0.0b	0.0b	0.001
Portulaca oleracea	14.6a	5.2b	3.0bc	2.9bc	1.8bc	2.4bc	0.7c	<0.0001
Sonchus oleraceus	7.9	5.9	4.9	4.8	5.1	6.7	4.4	0.28
Stellaria media	1.0a	0.0b	0.0b	0.0b	0.0b	0.0b	0.0b	0.03
Winter								
Conyza sp.	0.8	1.0	0.6	0.6	1.8	0.7	2.1	0.06
Capsella bursa-pastoris	8.2a	0.1b	0.5b	0.1b	0.3b	0.0b	0.0b	0.0003
Malva parviflora	6.4	4.9	2.0	3.4	1.2	1.7	1.3	0.06
Medicago poymorpha	3.8	4.6	1.4	3.0	1.3	1.7	1.4	0.06

[†]Means within a row followed by the same letter do not differ at the 5% level of significance of Fisher's Protected LSD test.

Portulaca oleracea continued to be present in the fall, and although differences between MeBr and the other fumigants were not observed, the 1,3-D:PIC plots with the VIF treatment had lower densities than the MeBr plots (Table 4). Other major species in the fall included *C. bursa-pastoris*, *Conyza* sp., *Lamium amplexicaule* L., *S. oleraceus*, and *S. media*. All the fumigants provided good control of *L. amplexicaule* and *S. media* compared to the nonfumigated treatments, however, the density of the other species were similar in all the treatments. Although *C. bursa-pastoris* densities were similar in the fall, its density was reduced by all the fumigants in winter. None of the fumigants reduced the densities of *M. parviflora* and *M. polymorpha*. Both these species have a hard seed coat (Egley, 1986; Wagner and Spira, 1994). The seeds of *M. polymorpha* and *M. parviflora* may not have been hydrated enough at the time of fumigation for the fumigants to penetrate the seed coat. *Medicago polymorpha* usually germinates and emerges after a significant rainfall event between September and December in California (Wagner and Spira, 1994). The fumigants were applied in May and the plots did not receive any rainfall or were not irrigated until much later in the year (fall).

Therefore, at this location all the alternative fumigants, except IM:PIC, were more effective than MeBr against *P. oleracea*. This was the only location where MeBr showed poor control of *P. oleracea*. It is not clear what other factors may have contributed to poor control of the resident seedbank of *P. oleracea* at this location. As observed in Yuba City, none of the fumigants provided adequate control of the Asteraceae weeds such as *Conyza* sp., *S. oleraceus,* and hard-seeded weeds such as *M. polymorpha* and *M. parviflora*.

At Hickman, there were more weed species present in densities greater than 1 plant m^{-2} than in the other locations. Spring samplings showed that *Amaranthus* sp., *C. bursa-pastoris*, *C. esculentus*, *Gnaphalium* sp., *Juncus bufonius* L., *P. annua*, *Salsola tragus* L., and *S. media* were controlled by all the fumigants compared to the nonfumigated plots (Table 5). *Stellaria media* was observed season-long but this species was suppressed by all the fumigants. However, the density of *Conyza* sp. was similar in all the plots. In the summer, all the fumigants suppressed *C. esculentus*, *Digitaria sanguinalis* (L.) Scop., and *P. oleracea* but were not effective against *S. vulgaris* and *S. oleraceus*. Ineffectiveness of the fumigants against these Asteraceae species was also observed in the fall and winter. In the winter, species such as *Anthemis cotula* L., *P. annua,* and *M. polymorpha* also emerged. While all the fumigants controlled the former two species, none controlled *M. polymorpha*.

CONCLUSIONS

This study showed that the tested alternatives, in general, had similar weed populations and community composition as MeBr in perennial nurseries.

TABLE 5 Seasonal Densities of Major Weed Species at Hickman, CA

Species	Treatment[a]							
	Control	MeBr	IM:PIC	1,3-D	1,3D:PIC-HDPE	1,3D: PIC (I)	1,3D: PIC-VIF	*P*-value
Density[†] (Plants m^{-2})								
Spring								
Amaranthus sp.	29.7a	0.0b	0.0b	0.0b	0.0b	0.0b	0.0b	0.03
Capsella bursa-pastoris	4.9a	0.2b	1.2b	0.1b	0.0b	0.1b	0.1b	0.001
Conyza sp.	0.5	0.4	0.6	0.3	1.0	0.6	0.6	0.89
Cyperus esculentus	1.6a	0.0b	0.0b	0.0b	0.1b	0.0b	0.0b	0.0002
Gnaphalium sp.	1.1a	0.4b	0.2b	0.2b	0.1b	0.2b	0.1b	0.05
Juncos bufonius	1.3a	0.0b	0.0b	0.0b	0.0b	0.2b	0.0b	0.002
Poa annua	1.5a	0.0b	0.0b	0.0b	0.0b	0.0b	0.0b	0.001
Salsola tragus	1.2a	0.1b	0.0b	0.1b	0.0b	0.0b	0.0b	0.003
Stellaria media	13.6a	0.5b	0.4b	0.4b	0.4b	0.2b	0.1b	0.0001
Summer								
Cyperus esculentus	4.8a	0.0b	0.4b	0.1b	0.0b	0.0b	0.0b	0.004
Digitaria sanguinalis	1.0a	0.0b	0.1b	0.0b	0.0b	0.0b	0.1b	0.001
Portulaca oleracea	1.4a	0.1b	0.2b	0.3b	0.1b	0.2b	0.1b	0.022
Senecio vulgaris	0.9	0.7	1.1	0.7	1.0	1.6	0.5	0.79
Sonchus oleraceus	1.0	0.6	0.5	0.6	0.4	0.4	0.4	0.69
Fall								
Conyza sp.	1.2	0.3	0.5	0.9	0.4	0.3	0.4	0.61
Sonchus oleraceus	0.8	1.8	1.1	0.9	1.0	1.1	1.5	0.79
Stellaria media	19.4a	0.0b	0.3b	0.0b	0.0b	0.0b	0.0b	<0.0001
Winter								
Anthemis cotula	1.2a	0.0b	0.0b	0.0b	0.0b	0.0b	0.0b	0.003
Conyza sp.	0.6	0.3	0.2	1.0	0.7	0.3	0.5	0.61
Medicago polymorpha	0.1	0.2	0.5	1.4	1.6	0.7	0.2	0.24
Poa annua	1.2a	0.0b	0.0b	0.0b	0.0b	0.0b	0.0b	0.008
Stellaria media	28.6a	0.0b	0.3b	0.1b	0.0b	0.0b	0.0b	<0.0001

[†]Means within a row followed by the same letter do not differ at the 5% level of significance of Fisher's Protected LSD test.

The type of plastic (HDPE or VIF) applied after fumigation had no effect on weed community composition. This could be because the soil was disturbed for bed preparation after the plastics were removed and this process could have stirred the soil seedbank and negated any effect of plastic types on weed species. The fumigants controlled most of the common weed species present including the troublesome species *C. esculentus* present at one location. However, hard seed-coated species such as *M. polymorpha*, *L. purshianus*, and *M. parviflora* were not adequately controlled by any of the alternate fumigants or MeBr. These species may remain as major weeds in perennial nurseries if alternative control measures are not used, because the seeds can remain viable in the soil seedbank for a long period. For example, a study showed that seeds of *M. polymorpha* and *M. parviflora* could remain viable in the soil for 200 years (Spira and Wagner, 1983). Similarly, all the fumigants were ineffective against Asteraceae weeds such as *Conyza* sp., *S. vulgaris*, and *S. oleraceus*. Additional weed control measures would, therefore, be required to manage these weed species in perennial nurseries. This research suggests that, in perennial crop nurseries, transitioning from MeBr to alternatives will not lead to a shift in weed species composition in the short-term.

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